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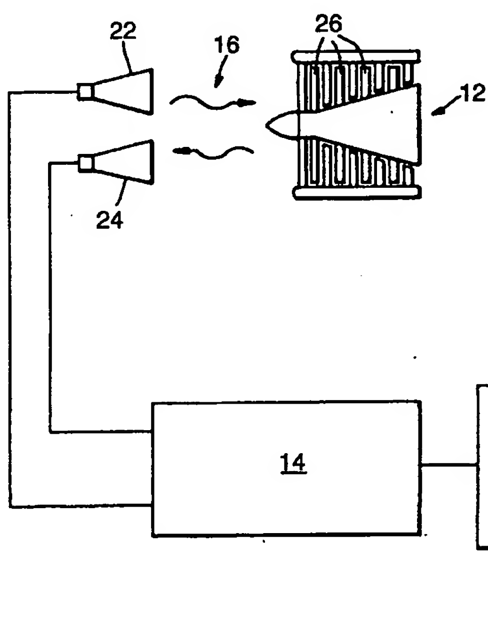

(57) Abstract

A system (10) for detecting damage to a gas turbine (12) of a jet engine has a radar transmitter (14, 22) and a radar receiver (14, 24). Radar signals (16) are transmitted at the turbine (12) and are reflected. Reflected signals are analysed in signal processing means (18). Damage in the turbine is determined by comparing a data sequence of measured siganals with a standard data sequence of previously measured signals.

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DAMAGE ASSESSMENT

This invention relates to a method of assessing damage in a turbine such as a gas or a steam turbine and is particularly, but not exclusively, concerned with jet engines for aircraft.

During the operational life of a turbine damage can occur to its blades. The term "blades" includes compressor blades and turbine blades. Damage can be caused by impact of objects drawn into the turbine or failure of parts within the turbine, for example, failure of the blades themselves. If initial damage is not spotted quickly further damage can occur in the turbine. Lost blades can unbalance a rotor stage which can, at least, cause excessive wear to the bearings of the turbine shaft. At most, it can cause failure of the turbine. Whilst failure will certainly be expensive, in some applications, such as gas turbines used in jet aircraft engines, failure can be dangerous.

It is an object of the invention to provide a method of monitoring damage in gas turbines.

It is a further object of the invention to provide a method of monitoring damage whilst the gas turbine is in operation.

According to a first aspect the invention provides a method of checking for damage in a turbine comprising the steps of transmitting a signal towards one or more rotating rotor stages of the turbine, detecting signals reflected by the or each rotor stage and analysing a record of the signals reflected.

Preferably the record is a time domain data sequence. To give information on the extent and perhaps the location of any damage, the record may be analysed in the time domain. Alternatively the record or selected parts of it may be converted into the frequency domain for analysis of its spectral components.

The record which is analysed may have features caused by modulation of the transmitted signal due to it being reflected by rotor blades in the or each rotor stage, or due to the signal reflected from some other part of the turbine being chopped by rotor blades in the or each rotor stage.

Preferably the record of the reflected signals is compared with a standard record. The standard record may have been produced by detecting signals reflected by an undamaged gas turbine or by the same turbine at an earlier time in its history.

Preferably the method uses radar signals.

Preferably the method uses coherent radar techniques.

Preferably amplitude and/or phase of reflected signals is used to determine a figure, value or other discriminant which is representative of damage in the particular turbine being measured. A figure, value or other damage discriminant may be generated by integrating a difference in the amplitude and/or phase of reflected signals across the record of the particular turbine being measured and amplitude and/or phase of reflected signals across the standard record.

The method may use probes for generating a signal, receiving signals or both. One or more

probes may be located within existing boroscope or inspection holes or apertures created specially in the body of the gas turbine (internal monitoring) thus allowing selected parts of the engine to be illuminated. Alternatively one or more probes may be mounted outside the rotor stages (external monitoring) for example, in or near the air intake. A hybrid method may use one or more probes for internal monitoring and one or more probes for external monitoring.

In an embodiment using internal monitoring each rotor stage may be provided with a transmitter and receiver system.

Preferably a continuous wave radar signal is used. This may be used in an application where ranging is not required. Alternatively pulsed radar ranging techniques could be used. This may be used in an application where ranging is required. If ranging is used, the method may be able to localise assessment of damage to a particular stage or even part of a rotor stage.

An advantage of the method is that inspection of rotor stages deep into the turbine can be performed without having to dismantle the engine. Furthermore, the level of damage in the turbine may be monitored whilst the turbine is in operation. Continuous monitoring is possible.

According to a second aspect the invention provides a system for assessing damage in a turbine comprising a transmitter which transmits a signal towards one or more rotating rotor stages, a receiver which receives signals reflected by the or each rotor stage and processing means which analyses a record of the signals reflected.

Preferably the record is in the time domain. It may be converted to the frequency domain for

analysis purposes.

Preferably the processing means compares the record against a standard record. The standard record may be a measurement of an undamaged gas turbine or of the same turbine at an earlier time in its history. Alternatively the standard record may be generated by calculation. The processing means may integrate differences in amplitude across the record and the standard record in order to determine a damage figure, value or other discriminant representative of damage of the particular turbine being measured.

The invention may be used to monitor turbines in a variety of applications including jet engines and turbines used in power generation.

An embodiment of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 shows a schematic representation of a damage monitoring system;

Figure 2 shows a frequency spectrum returned by two undamaged rotor stages;

Figure 3 shows a part of Figure 2 expanded;

Figure 4 shows the frequency spectrum of Figure 3 after further processing and with an alternative x-axis;

Figure 5 shows a frequency spectrum returned by a single undamaged rotor stage;

Figure 6 shows a frequency spectrum returned by a single rotor stage carrying a bent blade;

Figure 7 shows a comparison of two frequency spectra each returned by a single undamaged rotor stage;

Figure 8 shows a comparison of processed versions of Figures 5 and 6;

Figure 9 shows a comparison of two frequency spectra each returned by three undamaged rotor stages;

Figure 10 shows a comparison of two frequency spectra, one from an undamaged turbine and one from a damaged turbine;

Figure 11 shows another comparison of two frequency spectra, one from an undamaged turbine and one from a damaged turbine;

Figure 12 shows a comparison of two frequency spectra returned by a set of seven rotor stages;

Figure 13 shows a comparison between a frequency spectrum returned by an undamaged turbine and a frequency spectrum returned by a damaged turbine;

Figure 14 shows another comparison between a frequency spectrum returned by an undamaged

turbine and a frequency spectrum returned by a damaged turbine;

Figure 15 shows yet another comparison between a frequency spectrum returned by an undamaged turbine and a frequency spectrum returned by a damaged turbine;

Figure 16 shows a visual representation of an algorithm used in the analysis of time domain data collected by internal monitoring; and

Figures 17, 18 and 19 show three measurements of damage against location for different levels of damage obtained with internal monitoring.

Figure 1 shows a damage monitoring system 10 for monitoring a gas turbine 12. In this embodiment the gas turbine 12 was represented by a single compressor section in order to simplify the results to aid understanding. The system 10 comprises a radar system 14 for generating and receiving radar signals 16. The radar generates a continuous wave signal at an output power of a few tens of microwatts. The radar system 14 is controlled by a computer 18. The computer controls the radar operation and processing of received signals. Data generated by the computer 18 is stored in a data memory 20. The computer controls the transmitted waveform, digitisation and storage of received analogue signals, and signal processing and display functions.

In this embodiment external monitoring of the gas turbine is performed using standard gain horns 22, 24 one for transmitting signals and the other for receiving signals. In an embodiment using internal monitoring, transmitting and receiving probes are mounted close to the root of

the stator blades. As many current turbines have inspection and other ports for locating other types of sensors, such as for pressure, temperature and vibration it is possible to incorporate a miniature radar sensor in the available ports, without having any adverse effects on the performance of the turbine.

For internal monitoring, the beamwidth available from small radiating elements at 10GHz is suitable for illuminating a small section of a rotor blade stage at a time, as the turbine rotates. A cycle of the turbine would enable all the blades on the rotor stage to undergo detection by the system 10.

An alternative technique is a hybrid method using a combination of internal and external monitoring, which utilises a miniature radar probe mounted close to the wall of the air intake of the gas turbine and an internal probe.

A waveform generator in the radar system 14 produces an output which is up-converted to a continuous wave signal at I band, for example around 10 GHz. The signal is transmitted towards the gas turbine 12 through the horn 22. Signals reflected by gas turbine 12 are detected by the horn 24 and are down-converted, digitised and loaded into the computer for signal processing.

The continuous wave signal transmitted at the gas turbine is reflected off the compressor stages, other rotating parts and stationary parts of the gas turbine. In this example the gas turbine was rotated at approximately 1545 rpm which corresponds to a spool rate of approximately 25.75Hz, that is the number of revolutions of the shaft per second. Each compressor stage has a number

of blades (between 24 and 51) which generate a chopping rate which is the product of the number of blades on a compressor stage and the spool rate of the turbine. The continuous wave signal is thus modulated by the moving parts of the turbine into a frequency spectrum which is dominated by the spool rate and its harmonics.

Standard radar down-conversion techniques are used to convert the reflected signal to baseband In-phase (I) and Quadrature (Q) channels.

The baseband signal is digitised using a two channel analogue to digital converter. The digitisation rate is 500kHz per channel. The data are then down-loaded to the computer 18 for signal processing. At a sampling rate of 500kHz, a raw data file of approximately 25 Mbytes in size can be generated over 12 seconds of sampling. The raw data file contains baseband data centred about the offset carrier frequency of 100kHz (an offset carrier is employed to eliminate mains noise and for rejection of the image generated by mixing in the system). The data are converted into an appropriate format and then processed in blocks because of the large quantity of data.

Of course, a lower digitisation rate could be used for the spool rate mentioned above.

Each block of data first has the offset carrier frequency removed by digitally shifting the recorded signal to DC. This is performed by multiplying the data by a signal which is the complex conjugate of the offset carrier. Before a Fast Fourier Transform (FFT) can be performed on the time domain data to obtain a frequency spectrum, the data size has to be reduced, and as only the frequencies between -25kHz to +25kHz are of interest, a large amount

of the data is not required.

This redundant data is removed by using a time domain low pass filter with a cut-off frequency of ±25kHz. The data are filtered and decimated which results in a file which is small enough for the computer to carry out an FFT to produce a final processed frequency spectrum. The final spectrum has a bandwidth of ±25kHz and a resolution of about 1/12th Hz.

Figures 2 to 15 and 17 to 19 show results obtained by the system 10 in which a single compressor stage and external monitoring were used.

Figure 2 shows a frequency spectrum returned by two undamaged stages of rotors present in a gas turbine. The magnitude of the spectrum is presented and analysed in logarithmic form. It is composed of a comb-like structure of frequencies. The majority of the signal energy is held within a series of discrete frequency lines which occur at the spool rate and its harmonics. Extra information, in the form of spectral lines between the spool rate harmonics, exists which could also be analysed.

In this figure the results are measured over a period of approximately 12 seconds. Therefore, each frequency bin in the FFT represents about one twelfth of a hertz. However, the rotation rate of the gas turbine may vary by up to 1 rpm over the measurement period. This results in an uncertainty of approximately 1 part in 1,500 in frequency measurement. For example, a spool rate harmonic at 4 kHz will have an uncertainty of about 2.7 Hz. Hence the spool rate harmonics cannot be guaranteed to be in the same FFT frequency bin from result to result. Further processing of the returned spectrum is therefore required in order to allow for direct

comparison between respective spool rate harmonics. The computer is primed with an approximate value of a spool rate rpm and uses measurements from the input spectrum to improve, by iteration, the accuracy of the spool rate value.

The effect of scalloping loss is taken into account when calculating the magnitude of the spool rate harmonics. This loss is caused by the fact that the spool rate harmonics are not necessarily located in the centre of an FFT bin. If the frequency of the spool rate harmonic is located in between two FFT bins then the magnitude of the harmonic is greater than the signal magnitude in either of the individual FFT bins. To overcome this problem, interpolation is used to calculate the correct magnitude of the harmonic. A single magnitude value is calculated for each spool rate harmonic.

Figure 3 shows a section taken from Figure 2 expanded to show the reduced frequency range ±5kHz. Figure 4 shows the corrected spool rate harmonic response calculated to take account of scalloping loss discussed above. With one sample per spool rate harmonic, comparisons can thus be made between results measured at differing engine spool rates. An x-axis value of 50 corresponds to the frequency component measured at 50 times the spool rate.

Figures 5 to 8 show results obtained using a single rotor stage in the gas turbine. Although in practice many more stages would be present (for example seven or more) simplified results are shown to illustrate the invention. The single rotor stage has 25 blades. This gives rise to a chopping rate of approximately 645Hz. Figure 5 shows a spectrum of the returned signal for a complete and undamaged first rotor stage. The DC component shows the strength of the signal which has been returned from stationary parts of the engine and its surroundings.

Dominant frequency components occur at the chopping rate and its harmonics. Since the first stage of rotors has 25 blades, the radar return from the gas turbine should repeat every time the engine shaft rotates by 1/25th of a revolution. This modulation gives rise to the dominant lines in the spectrum at harmonics of the chopping rate. Also in the spectrum at a lower level, distinct frequency components can be seen which occur at the spool rate and its harmonics.

Figure 6 shows a spectrum returned by a single rotor stage having a bent blade. The bent blade was twisted along its length. Dominant frequency components still occur at the chopping rate and its harmonics. This shows that, as expected, a marked repetition is still occurring in the radar return signal each time the shaft rotates through 1/25th of a revolution.

Figure 7 shows the difference between the spool rate harmonic responses of two undamaged single rotor stage frequency spectra. Since it is the difference of two sets of logarithmic data which is plotted, the plot actually shows the ratio of the two responses at each spool rate harmonic. There is relatively little variation between the two results. The plotted line becomes "noisier" at higher harmonics, because the signal to noise ratio of the individual responses is lower. Hence their difference is more affected by variations due to noise.

A damage meter reading which gives a numerical value as a measure of the differences between two results has been developed. The magnitude of the difference between the two results is averaged across the spool rate harmonics, having allowed for small speed variations in the spool rate. The resulting mean value is taken as the damage meter reading when a damaged turbine is compared with an undamaged turbine which is used as a reference. The larger the damage meter reading, the more significant the differences between mechanical states of the engine as

measured by the radar. The consistency of damage meter reading can be used to provide a measure of the repeatability between measurements.

Figure 8 shows the ratio of the spool rate harmonic response for the result in Figure 6 over the spool rate harmonic response of the result shown in Figure 5 and gives a comparison between frequency spectra returned by an undamaged rotor stage and a rotor stage having a bent blade.

Figures 9 to 11 show frequency spectra returned by three rotor stages present in the gas turbine. The first stage has 25 blades which gives a chop rate of approximately 645Hz as above. The second rotor stage has 37 blades which gives a chop rate of approximately 955Hz. The third rotor stage has 51 blades which gives a chop rate of approximately 1315Hz.

Figure 9 shows the ratio of spool rate harmonics comparing two frequency spectra returned by the gas turbine having three undamaged rotor stages.

Figure 10 shows a comparison of a spectrum recorded with three undamaged rotor stages being present, and another spectrum which has three rotor stages present with a damaged blade in the third rotor stage. The damaged blade has had a corner removed, with the loss of approximately 5% to 10% of the blade area.

Figure 11 shows a comparison of a spectrum, recorded with three undamaged rotor stages being present, and another spectrum recorded with three rotor stages present, there being a bent blade in the third rotor stage.

As the number of rotor stages increases returned frequency spectra become more complex. This is due to the multitude of reflections causing large amounts of multipathing and mixing products. This will partly be due to different compressor stages having different numbers of blades and consequently different chopping rates. It results in a more crowded spectrum where individual chopping rate peaks are less obvious. Chopping rate peaks from further back in the compressor are much less dominant because reflected signals have to pass through a number of compressor stages and stators.

A sequence of measurements made with damaged blades are shown in figures 12 to 15. They are based on results returned from a gas turbine having five rotor stages.

A standard spectra difference plot is Figures 12. Figures 13 to 15 are difference plots for:

(i) a damaged blade on the third stage versus reference (Figure 13);

(ii) a damaged blade on each of the third and fourth stages versus reference (Figure 14); and

(iii) a damaged blade on each of the third, fourth and fifth stages versus a reference (Figure 15).

As can be seen from the figures, as the number of damaged blades increases, the amount of difference increases. Using the damage meter these differences can be represented by a single numerical value. The damage meter value for undamaged rotor stages for Figure 12 is 0.22, for Figure 13 is 1.04, for Figure 14 is 1.64 and for Figure 15 is 1.72.

It is desirable to determine exactly where in the turbine the damage is present. In another embodiment of the system, the radar system 14 is used with internal probes instead of the horns

22 and 24. The probes are fitted in inspection or boroscope holes in the turbine so that the reflected signals received come predominantly from one rotor stage. Multiple probes may be used to monitor several rotor stages. In this way damage may be localised to a particular rotor stage. Furthermore, it is possible to determine which blade in the rotor stage is damaged by processing the data record in the time domain. This is carried out by isolating an individual cycle of the rotor, determining the time within the cycle when damage is indicated and calculating the angular displacement of the damaged blade from a reference blade.

This kind of damage localisation is not possible using spectra in the frequency- domain. To obtain a high resolution in frequency, data must be collected over many turbine cycles which makes obtaining specific timing information difficult. However, if data are recorded in the time domain, changes (due to a damaged blade going past) can be noted as they occur. This allows the damaged blade to be identified within an engine cycle-period.

Disruption of the radar beam by moving blades produces a fluctuation in the received signal. The fluctuation caused by a normal blade has a characteristic shape. A damaged blade produces a different kind of disruption and hence a different signal shape. Detecting different signal shape is carried out using a correlation technique. This is a method of comparing the general shape of two signals which is unaffected by overall differences in mean level. It can be represented by a correlation coefficient which is a single number quantifying how similar two signals are to each other - a value of 1 means that they are identical, whereas a value of 0 indicates that they are completely dissimilar.

By correlating a section of data obtained from the turbine in a damaged state with a section of

reference data, the correlation coefficient can be calculated. This value becomes lower as the two data sections become increasingly dissimilar (in whatever way) due to increased blade damage.

The correlation coefficient can also be used as an indicator of position within the turbine cycle. With every revolution, the same part of the turbine comes into the view of the transceiver probe, and hence signals of the same general shape as in the previous revolution will be picked up. If a short section of signal is recorded, and the start of this is denoted as the start of a cycle, then where a signal section of the same shape is next encountered will be the start of the next cycle. In this way, data corresponding to a single cycle can be isolated from a mass of data which may have been obtained over many turbine revolutions.

An algorithm used to analyse a recorded data series is shown in Figure 16. It comprises three main operations.

Operation 1

An arbitrary portion of reference data is selected, and denoted as the start of a cycle. Then using the correlation coefficient as a measure of similarity between one signal shape and another, a search is made onwards from the start to find where that portion of data reference next occurs in the sequence of reference data. This marks the start of the next cycle, and hence the end of the cycle being considered. As a result a complete reference cycle 30 is isolated. The same procedure is adopted for the recorded data obtained from the measured turbine. As a result of this, a complete recorded cycle 32 is isolated. This will be broadly similar to the cycle 30 obtained from the reference data apart from any local difference caused by damage. The

recorded cycle 32 and the reference cycle 30 are, so far, unaligned. The cycles which are produced have a signal level 28 which varies with angular position.

Operation 2

The reference and recorded cycles (30, 32) are roughly aligned. This is done by correlating the whole of one cycle with the whole of the other. The effect of doing this is essentially to rotate the recorded cycle until it matches up with the reference cycle, an optimum match position being achieved where there is a peak in the value of the correlation coefficient. Damage will degrade the quality of the match since matching is done over the entire cycle. However, even if the damage is extreme, the alignment is sufficiently good to allow refinement of alignment.

Operation 3

A small section 34 of the reference cycle 30 is selected and sought in a corresponding section 36 of the recorded cycle 32. The section of reference data is shifted point by point through the recorded cycle 32 and the correlation coefficient calculated for each shift. Where the section 34 of the reference cycle 30 best matches the section 36 of the recorded cycle 32 is indicated by a peak in the correlation coefficient, and the value obtained at that point is used directly as a measure of the similarity. The whole process is repeated many times, with neighbouring sections of reference cycle 30 data being compared with their corresponding sections of the recorded cycle 32. The search sections in the recorded cycle 32 are larger than the sections in the reference cycle 30 to allow for any misalignment in the reference and recorded cycles from Operation 2. At each iteration, the value of correlation coefficient obtained can be used to generate a damage reading which can be plotted at the relevant position on a circular dial 38. Whichever iteration includes the region in the recorded cycle where damage is present will

return a marked difference 40 of the correlation coefficient to the rest of the cycle. The size of the difference 40 will reflect the size of the blade damage, and the position of the damage reading on the dial will correspond with the position of the damaged blade in the rotor stage.

Readings on the output dial will also be due to factors other than damage to a turbine blade.

One cause of variation in the output reading is the variation in the amplitude of the data themselves, a consequence of the fluctuation in the radar signal caused by the passage of the turbine blades between the transmit and receive points of the internal monitoring probe. This fluctuation is such that the signal is alternately weak and strong. When weak, the influence of thermal noise is not negligible. Since thermal noise is uncorrelated, a small-scale comparison of reference with recorded data (as described in Operation 2) will result in a low value of correlation coefficient, similar to a result obtained in the case of a damaged blade.

Another cause of variation in the output signal is turbine speed variation. The effect of this variation of speed in the time-domain data obtained from the turbine is one of regular contraction and expansion of the time axis. It is for this reason that the processing algorithm compares the reference and test cycles in small sections (Operation 3). These sections are small enough so that, over their duration, the effects of speed variation in the turbine can be regarded as negligible. However, the smaller the sections, the fewer the number of points from which the correlation coefficient is calculated. As the size of its sample is reduced, the correlation coefficient is subject to increasing amounts of statistical error.

In an attempt to limit the unwanted variation in the output signal, the time-domain processing

algorithm incorporates two further operations, subtraction and integration.

To distinguish unwanted variation in the output damage reading from the similar, desired, variations which are caused by a damaged blade, the unwanted variations are characterised. To do this the time-domain algorithm is run with two references as the input data. Reference plus recorded data (with the effect of blade damage present) produces unwanted returns plus those due to the damage. Reference plus reference (with no blade damage) produces the unwanted returns alone.

Once obtained, the output dial readings for the unwanted variations can be subtracted from those which were obtained by comparing a reference with a recorded data series. This results in rejection of the unwanted variations and allows variations due to blade damage to remain.

The last operation in the time-domain processing algorithm uses integration. The whole of the algorithm (Operations 1, 2 and 3, followed by subtraction) is repeated for many different cycles of the data. After each iteration the resultant set of damage readings is aligned with the previous set and added to it to produce a single, overall output. This reinforces the more constant parts of the output (due to damage which is always present) against the less constant backdrop, due to the various types of unwanted fluctuation.

Figures 17, 18 and 19 show results obtained with different levels of turbine damage using the radar system having internal transceiver probes instead of horns 22 and 24. The horizontal axis is the angular position within the turbine cycle having a range from 0 to 359, with a resolution of 1 degree. The vertical axis denotes the level of damage reading. Figures 17, 18 and 19 show

percentage areas of blade removed equivalent to 0.05%, 0.2% and 0.74% respectively. Each figure was generated by integrating eight cycles together. Small negative values of "damage level" can arise in regions where the signal to noise ratio is poor, due to the process of subtracting the unwanted variation. They should be regarded as statistical fluctuations about zero rather than "negative damage".

No damage is readily apparent in figure 17. Figure 18 marks an approximate limit at which blade damage can be detected by the time-domain algorithm. A peak is evident at 38° although it is close to the background level. In Figure 19, the sharp peak at 38° shows damage to a blade at that angular position.

Although internal monitoring techniques out perform those of external monitoring in terms of sensitivity achieved both methods have their uses. Internal monitoring uses either existing boroscope holes or holes appropriately provided in which the miniature probes are located. The probes may be passive antenna elements connected to a transmitter or receiver via a microwave cable. The active microwave circuitry and signal processing components are located in a less severe environment, and do not need to meet the temperature and pressure requirements at the boroscope holes.

For external monitoring several equipment configurations are possible. It may be provided as a "hand-held" unit totally remote from the gas turbine. However, locating a miniature probe in the engine air intakes is preferred, either in the form of a probe permanently fixed to the engine or one installed for servicing purposes on locating lugs. The associated electronics could either be permanently installed on the aircraft or be part of the maintenance facility,

attached to the probe by a cable. Permanent installation on the aircraft would allow continuous monitoring to take place in flight. Otherwise, it would enable tests to be performed during servicing.

Higher range resolution radar techniques can provide localisation of blade damage to a particular stage when external monitoring is used or can improve the localisation to a particular stage when internal monitoring is used. In order to localise damage reliably to a particular rotor stage, it is necessary to generate and process a radar pulse with a range resolution of a few centimetres, which is typical of the spacing between rotor stages.

Coherent Doppler radar techniques allow both amplitude and phase information from the engine to be obtained on a continuous basis. These enable small mechanical changes and damage to the blades to be detected. In addition, fluttering blades may have characteristic Doppler frequency spectra, and measurement of these effects could be used as a discriminant to identify the presence of flutter.

The technique can be used to detect damaged or missing blades, and detect flutter of blades. It may be also be used as a diagnostic aid during engine development.

The technique may be used to monitor gas turbines in jet engines for aircraft, in centrifugal compressors for helicopters and in power generation applications.

CLAIMS

1. A method of checking for damage in a turbine comprising the steps of transmitting a signal towards one or more rotating rotor stages of the turbine, detecting signals reflected by the or each rotor stage and analysing a record of the signals reflected.

2. A method according to claim 1 which uses radar signals.

3. A method according to claim 1 or claim 2 in which the record is a time domain data sequence.

4. A method according to claim 3 in which the record is analysed in the time domain.

5. A method according to claim 3 or claim 4 in which the record or selected parts of it are converted into the frequency domain for analysis of its spectral components.

6. A method according to any preceding claim in which the record of the reflected signals is compared with a standard record.

7. A method according to claim 6 in which the standard record is produced by detecting signals reflected by an undamaged gas turbine or by the same turbine at an earlier time in its history.

8. A method according to any preceding claim in which amplitude and/or phase of

reflected signals is used to determine a figure, value or other discriminant which is representative of damage in the turbine.

9. A method according to claim 8 as it depends on claim 6 or claim 7 in which the damage discriminant is generated by integrating a difference in the amplitude and/or phase of reflected signals across the record of the turbine and amplitude and/or phase of reflected signals across the standard record.

10. A method according to any of claims 2 to 9 in which a continuous wave radar signal is used.

11. A method according to any of claims 2 to 9 in which pulsed radar ranging techniques are used.

12. A method according to any of claims 2 to 11 which uses coherent radar techniques.

13. A method according to any preceding claim which is used to monitor turbines in jet engines.

14. A method substantially as described herein with reference to the accompanying drawings.

15. A system for assessing damage in a turbine which operates in accordance with any preceding claim comprising a transmitter which transmits a signal towards one or more

rotating rotor stages, a receiver which receives signals reflected by the or each rotor stage and processing means which analyses a record of the signals reflected.

16. A system according to claim 15 which comprises probes which may be located within existing boroscope or inspection holes or apertures created specially in the body of the gas turbine thus allowing selected parts of the engine to be illuminated.

17. A system according to claim 15 or claim 16 in which the or each rotor stage is provided with a transmitter and receiver system.

18. A system according to any preceding claim in which one or more probes are mounted outside the rotor stages.

19. A system substantially as described herein with reference to the accompanying drawings.

Fig.1.

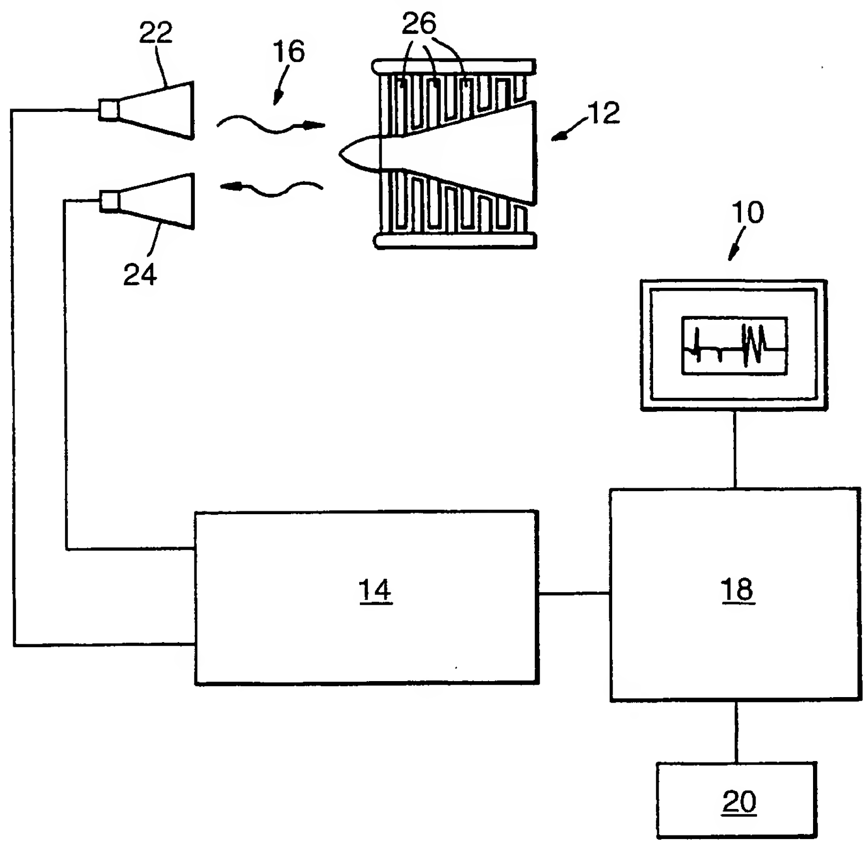
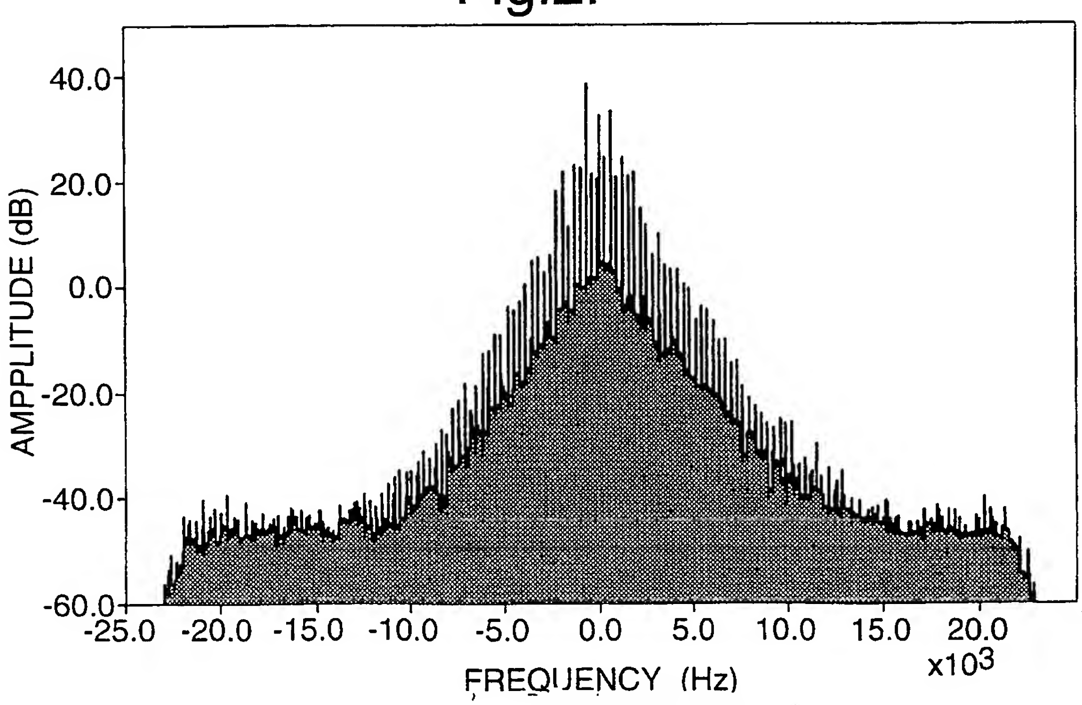

22
16
26
12
24
10
14
18
20

Fig.2.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20.0
0.0
-20.0
-40.0
-60.0
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-20.0
-15.0
-10.0
-5.0
0.0
5.0
10.0
15.0
20.0
x10^3
FREQUENCY (Hz)

Fig.3.

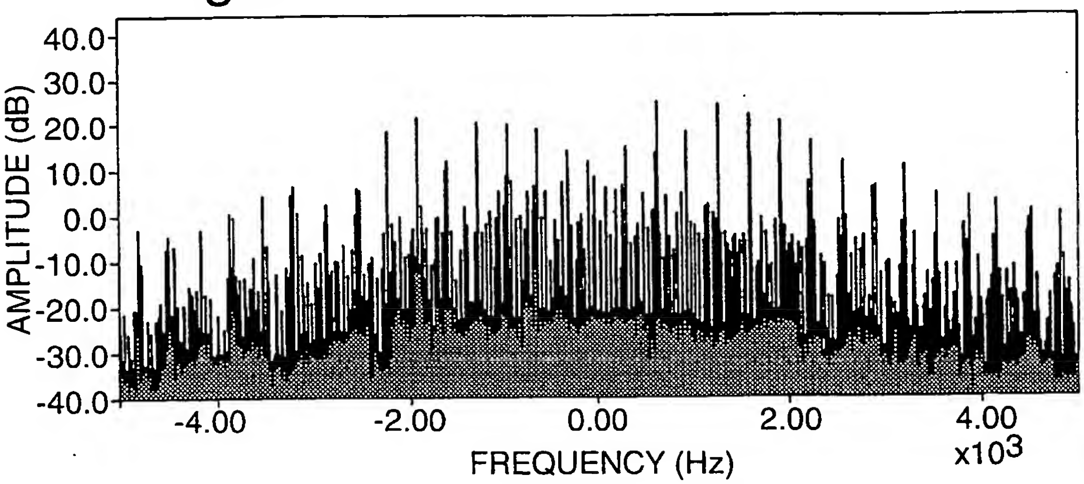


Fig.4.

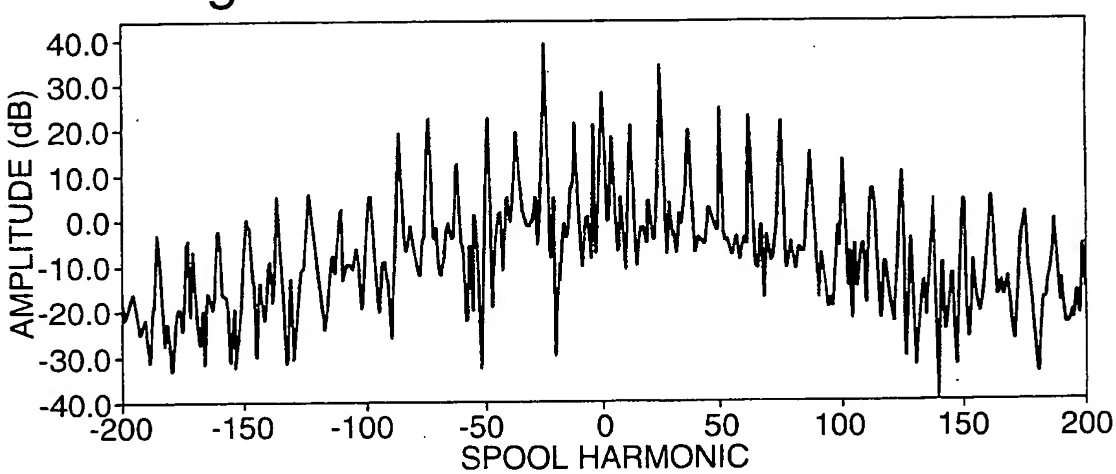


Fig.5.

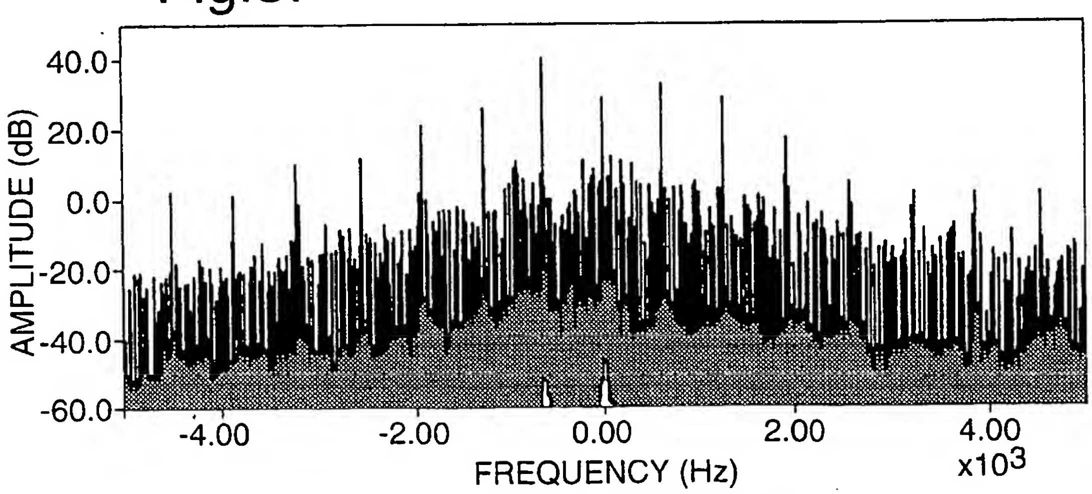
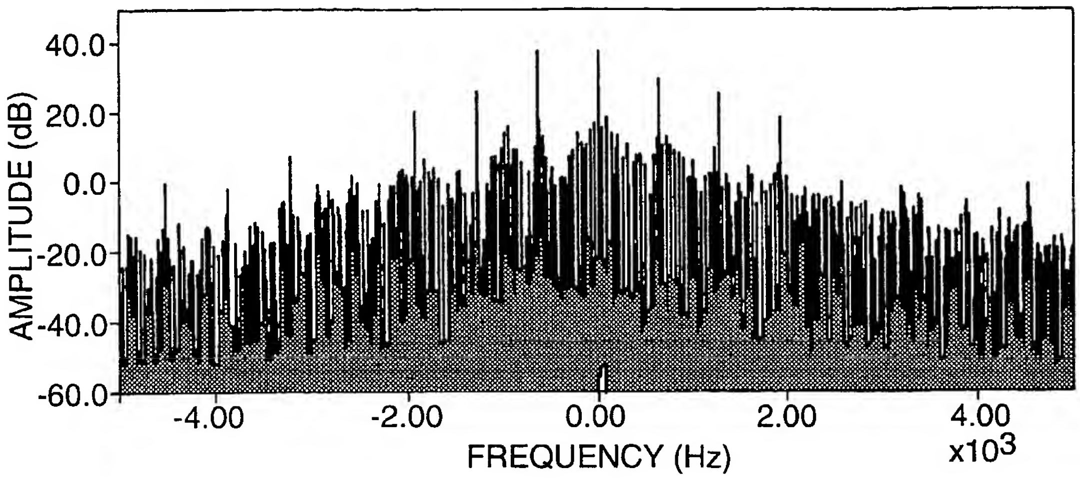


Fig.6.



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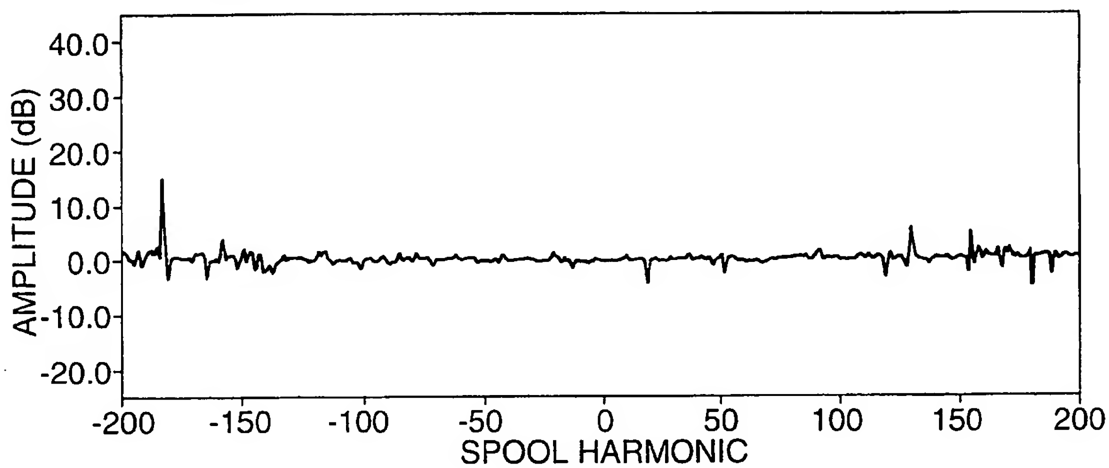


Fig.8.

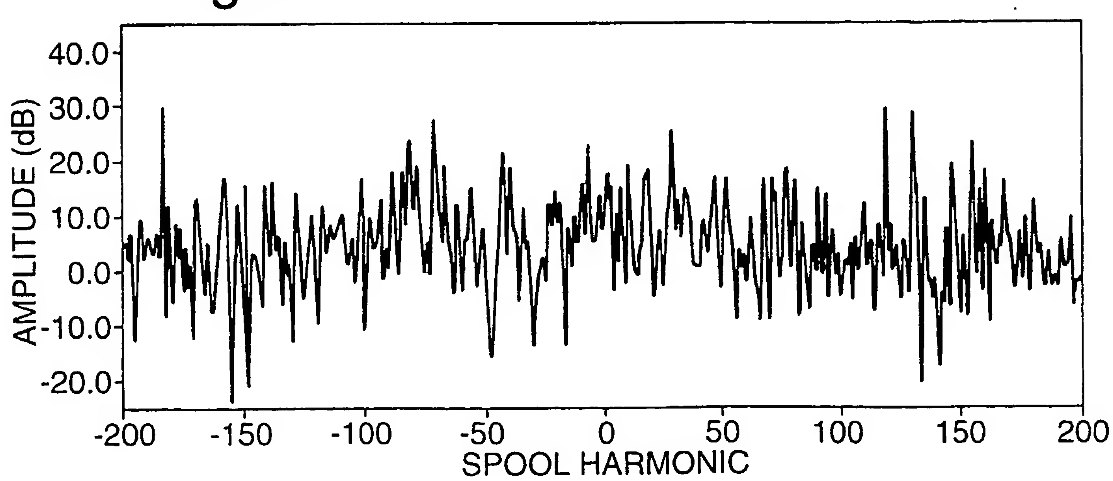
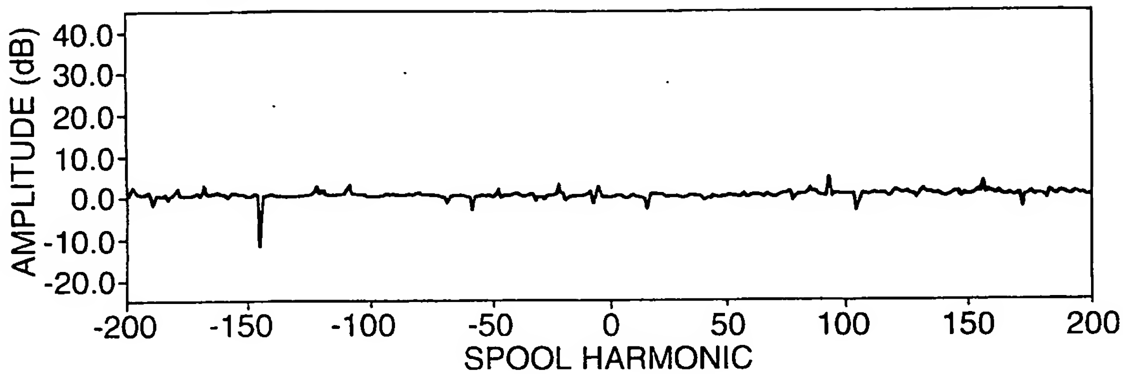


Fig.9.



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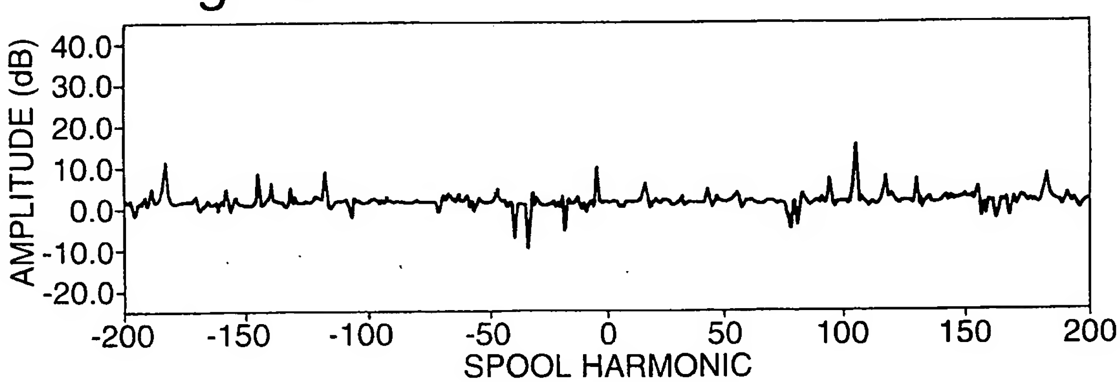


Fig.11.

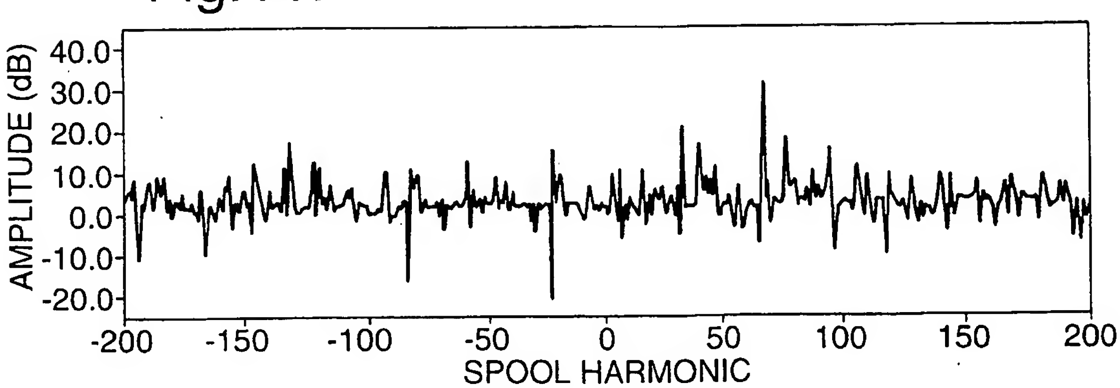


Fig.12.

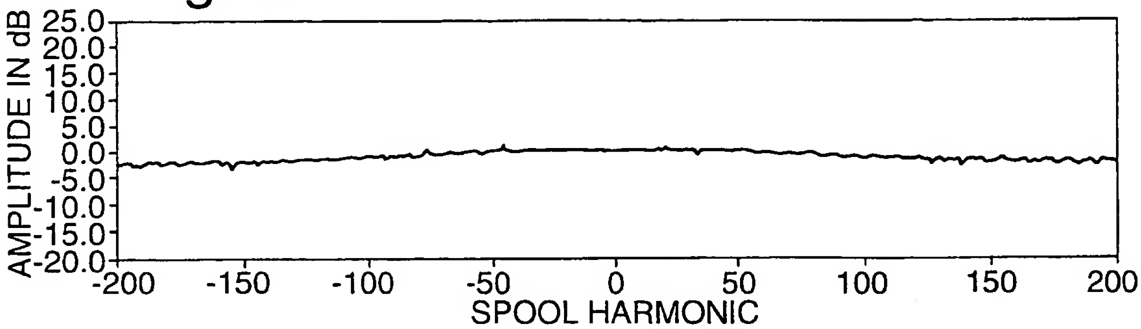


Fig.13.

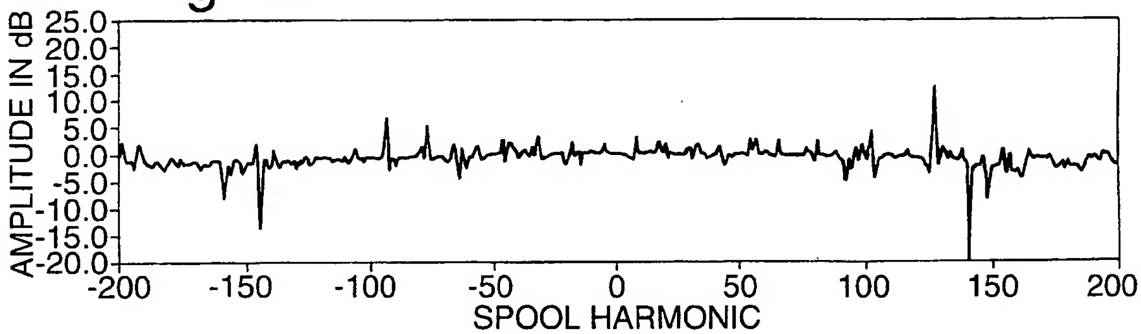


Fig.14.

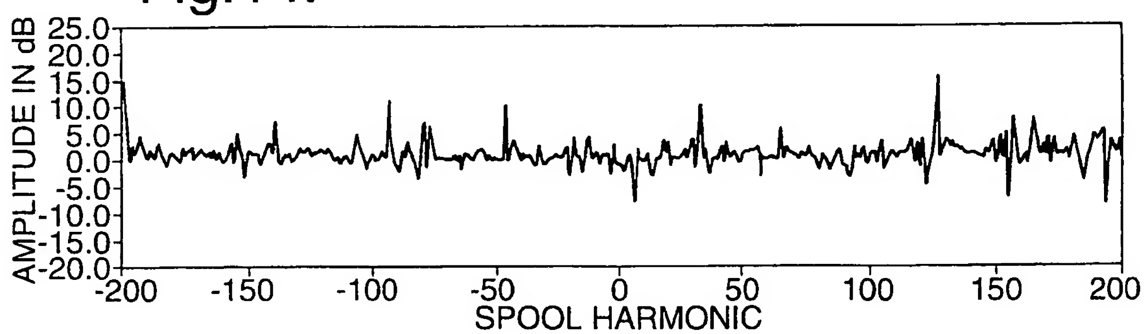


Fig.15.

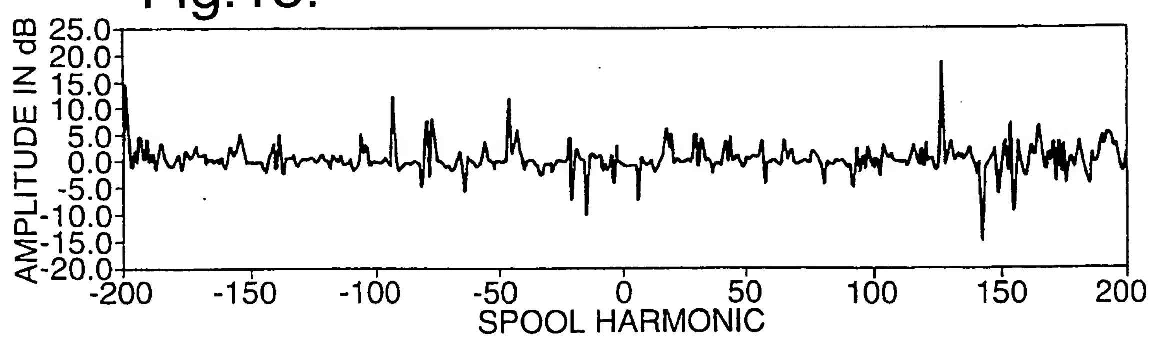


Fig.16.

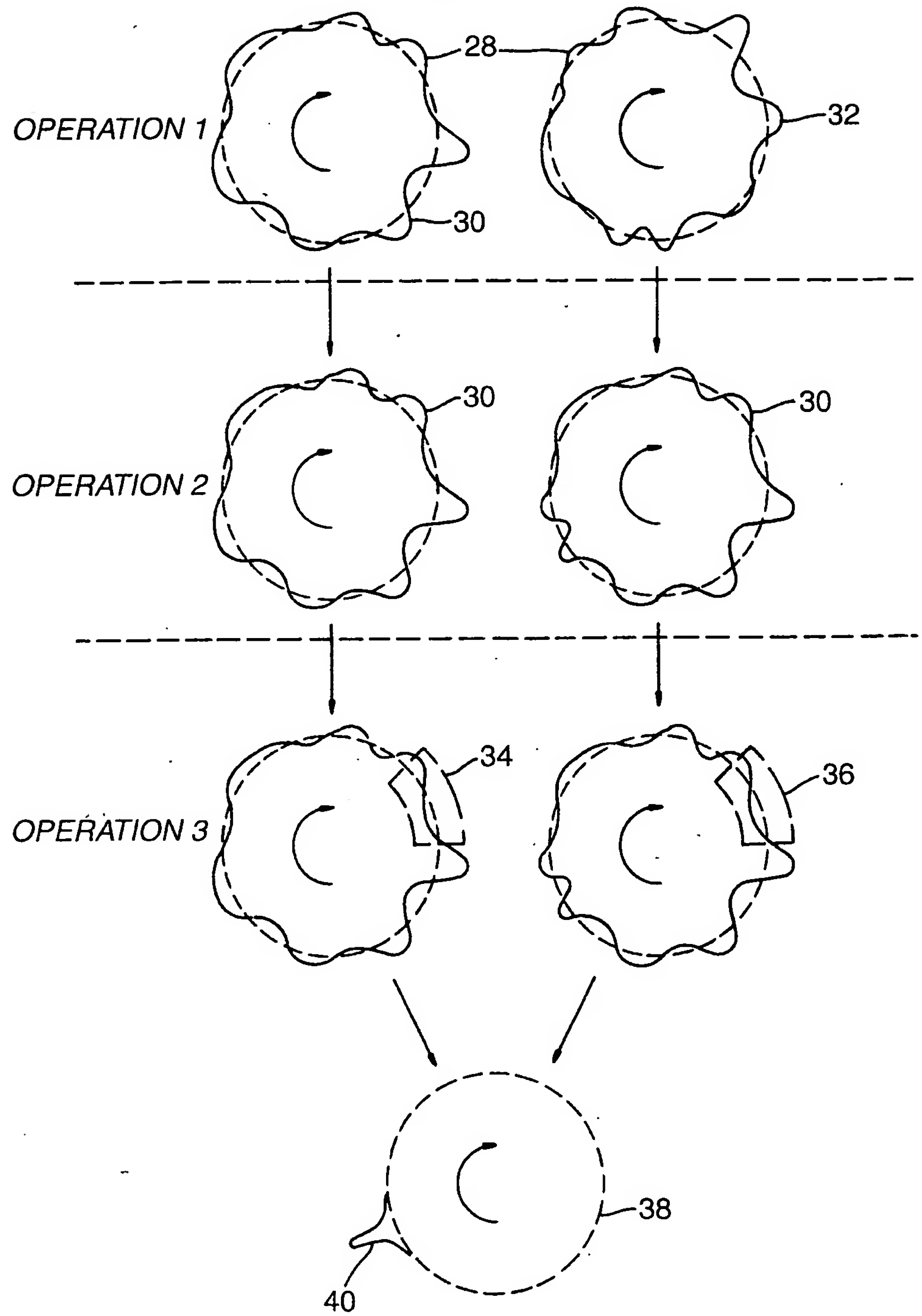


Fig.17.

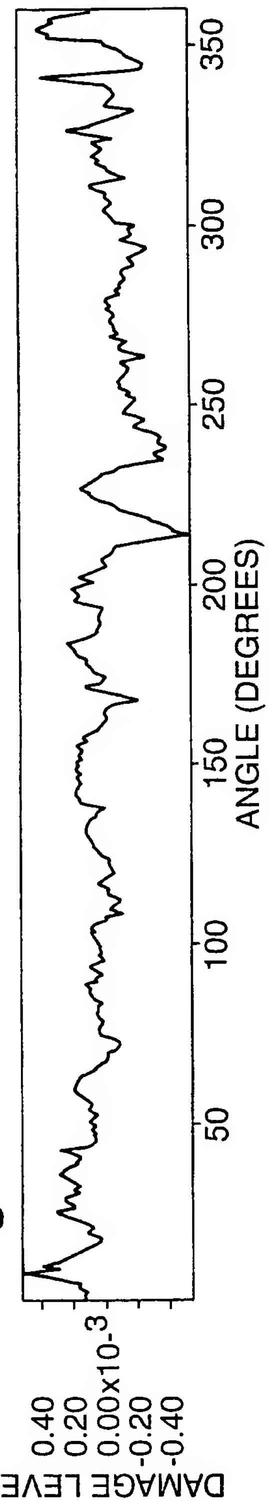


Fig.18.

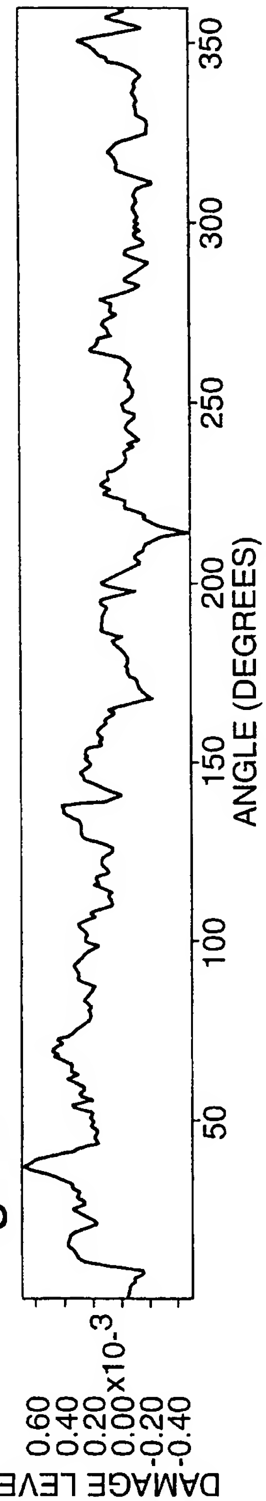
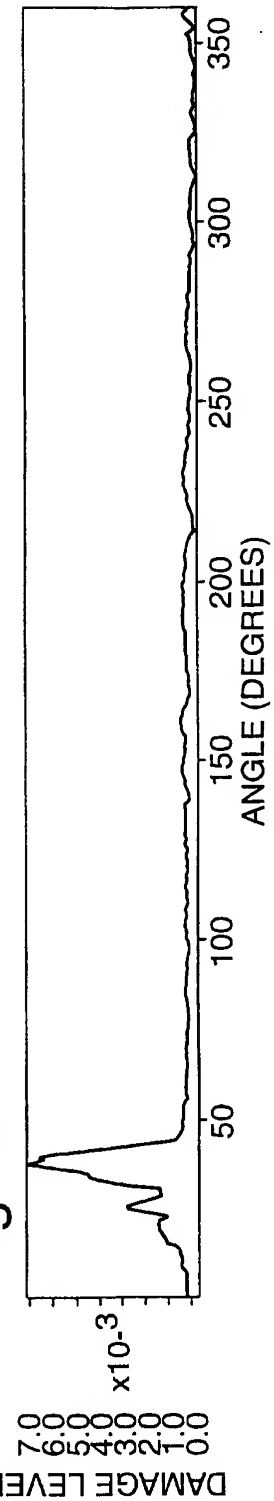


Fig.19.



INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 98/00698

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G01S13/88 F01D21/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G01S F01D G08B G01H G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 95 35484 A (WESTINGHOUSE ELECTRIC CORP) 28 December 1995 see abstract; figure 4	1,2
Y	US 4 413 519 A (BANNISTER RONALD L ET AL) 8 November 1983 see column 4, line 54 - column 5, line 28; figures 5-7	1,2
A	DE 40 17 448 A (SIEMENS AG) 6 December 1990 see claim 1	1
A,P	WO 97 22891 A (FISHER CONTROLS INT) 26 June 1997 see abstract; claim 1; figure 1	1,2
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
7 July 1998	14/07/1998

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 98/00698

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	GB 2 065 410 A (SMITHS INDUSTRIES LTD) 24 June 1981 see abstract; figure 1 -----	1

1

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
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